NATIONAL URANIUM TAILINGS PROGRAM

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Canada

AN INVESTIGATION OF AQUATIC COMMUNITIES EXPOSED TO URANIUM TAILINGS EFFLUENTS

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EXECUTIVE SUMMARY

We surveyed the chemical and biological characteristics of five aquatic environments that were being influenced by acidic, high-sulfate effluents from five inactive uranium tailings areas located near Elliot Lake, Ontario. Our purpose was to provide background information necessary for the effective planning of long term or intensive studies on the ecological impacts of such effluents. Field work was conducted primarily during summer and fall in 1984 and 1985.

A portion of Buckles Creek was investigated because it had apparently begun to be influenced by a small plume of underground seepage from the Nordic Main Tailings Area. Despite the obvious yellow-orange preciptates which appeared at and below the seepage zone, our data indicated that the seepage was having relatively minor chemical and biological effects on the creek. Its impacts will probably not increase substantially until the "core" of the seepage plume eventually nears the creek channel, and this may not occur for many years. Buckles Creek should be an excellent model site in which to document the progressive consequences of a high-sulfate seepage entering a small waterway.

Westner Lake, Lacnor Pond, Olive Lake and Beaver Lake were small lakes receiving effluents, respectively, from the Nordic West Arm Tailings, Lacnor Tailings, the Spanish American Tailings and the Stanrock Tailings. All of these lakes were acidified [pH 3 or less] and exhibited elevated concentrations of sulfate, aluminum, iron and other

elements. Observed concentrations of 226-radium were relatively low, ranging from about 3 pCi/L in Westner Lake to about 30 pCi/L in Olive Lake. Benthic studies in Westner Lake showed that sediments were being acidified and leached of various metals. In general, Beaver Lake had the most extreme chemical impairment. Lacnor Pond and Beaver Lake were chemically stratified, but Westner and Olive Lakes were not. All four lakes were chemically harsh aquatic environments, and uninhabitable by certain groups of aquatic animals [e.g. crustaceans, fish, amphibians], but they nevertheless all supported aquatic mites and several types of freshwater insects. Beaver Lake supported the fewest insects, but their numbers were also very low in Westner Lake, the lake exhibiting the least extreme chemical conditions. Insect denisty was therefore not well correlated with the intensity of water quality impairment. The immature stages of chironomid flies [midges] were generally the most numerous insects, but water boatmen, caddis fly larvae, beetle larvae and alderfly larvae were common. The latter three are predaceous. Insect types were much the same among lakes, and the mites and all of the more numerous insects appeared to be completing their life cycles satisfactorily. Overall, these findings indicated that detailed biological data from one tailings-inluenced lake would have wide applicability to others, and that simple food chain studies would be feasible where biomagnification of radionuclides or other elements is of interest.

INVESTIGATION OF AQUATIC COMMUNITIES EXPOSED TO URANIUM TAILINGS EFFLUENTS

INTRODUCTION

This project was undertaken to provide background information for planning long term and/or intensive studies on the bio-limnological impacts of effluents from inactive uranium tailings areas, near Elliot Lake, Ontario.

In the late summer and autumn of 1984 we investigated the chemical characteristics and faunas of Buckles Creek and Westner Lake [Fig. 1], sites which were receiving small volumes of seepage from the Nordic Main and Nordic West Arm tailings areas respectively. In the summer of 1985 we continued examining the water quality and benthos of Westner Lake, and also obtained equivalent data from three other lakes associated with inactive tailings [Beaver Lake, Lacnor Pond and Olive Lake]. Beaver Lake was receiving treated effluent and seepage from the Stanrock Tailings Area, Lacnor Pond was in contact with the Lacnor Tailings, and Olive Lake was in contact with the Spanish American Tailings [Fig. 2].

A 1.5 km segment of Buckles Creek was chosen for study for several reasons. It was a relatively small but essentially permanently flowing waterway, it was easily accessible, and it was apparently being influenced by the

Figure 1. Locations of Buckles Creek, Westner Lake, and their associatied tailings areas, near Elliot Lake, Ontario.

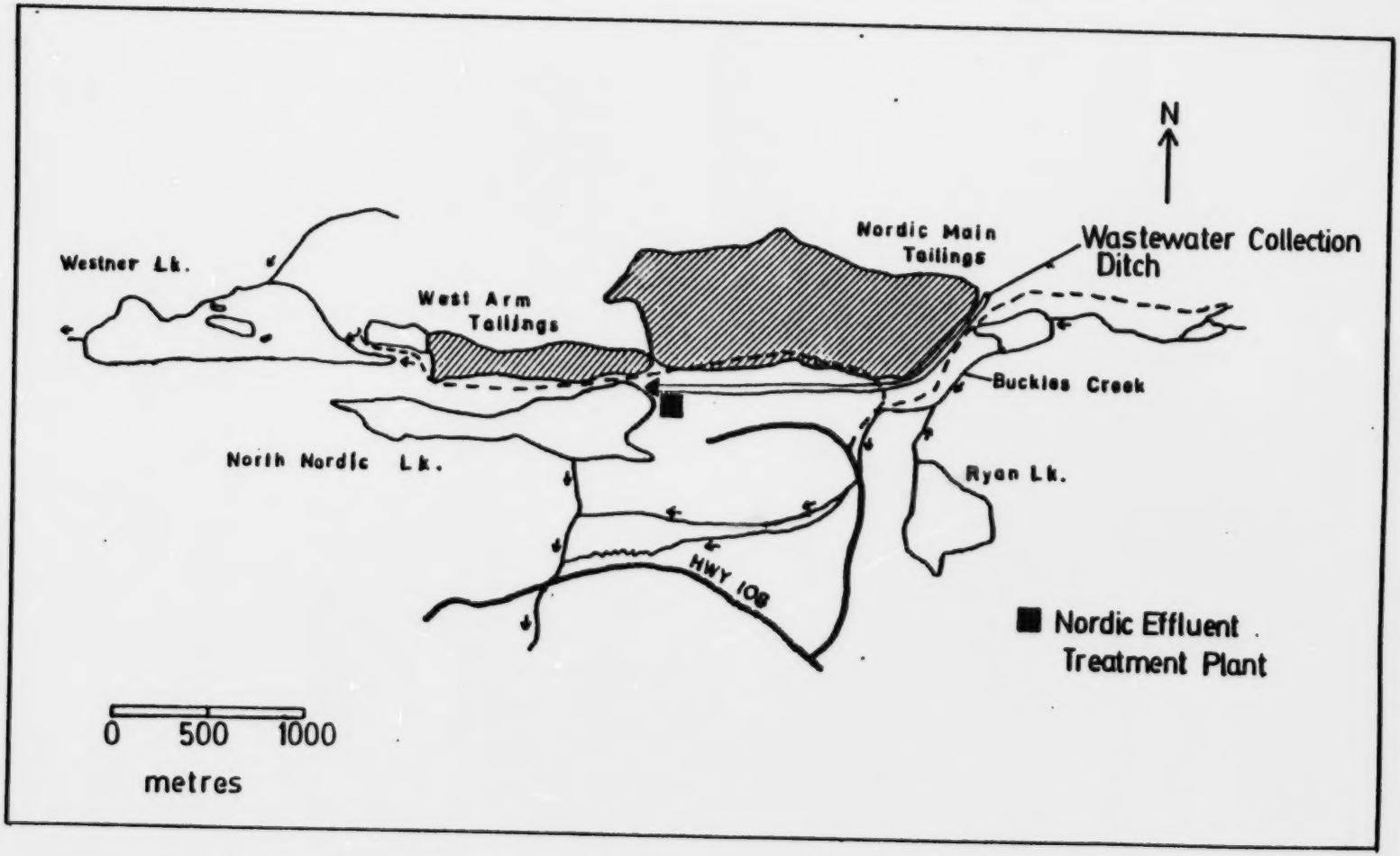
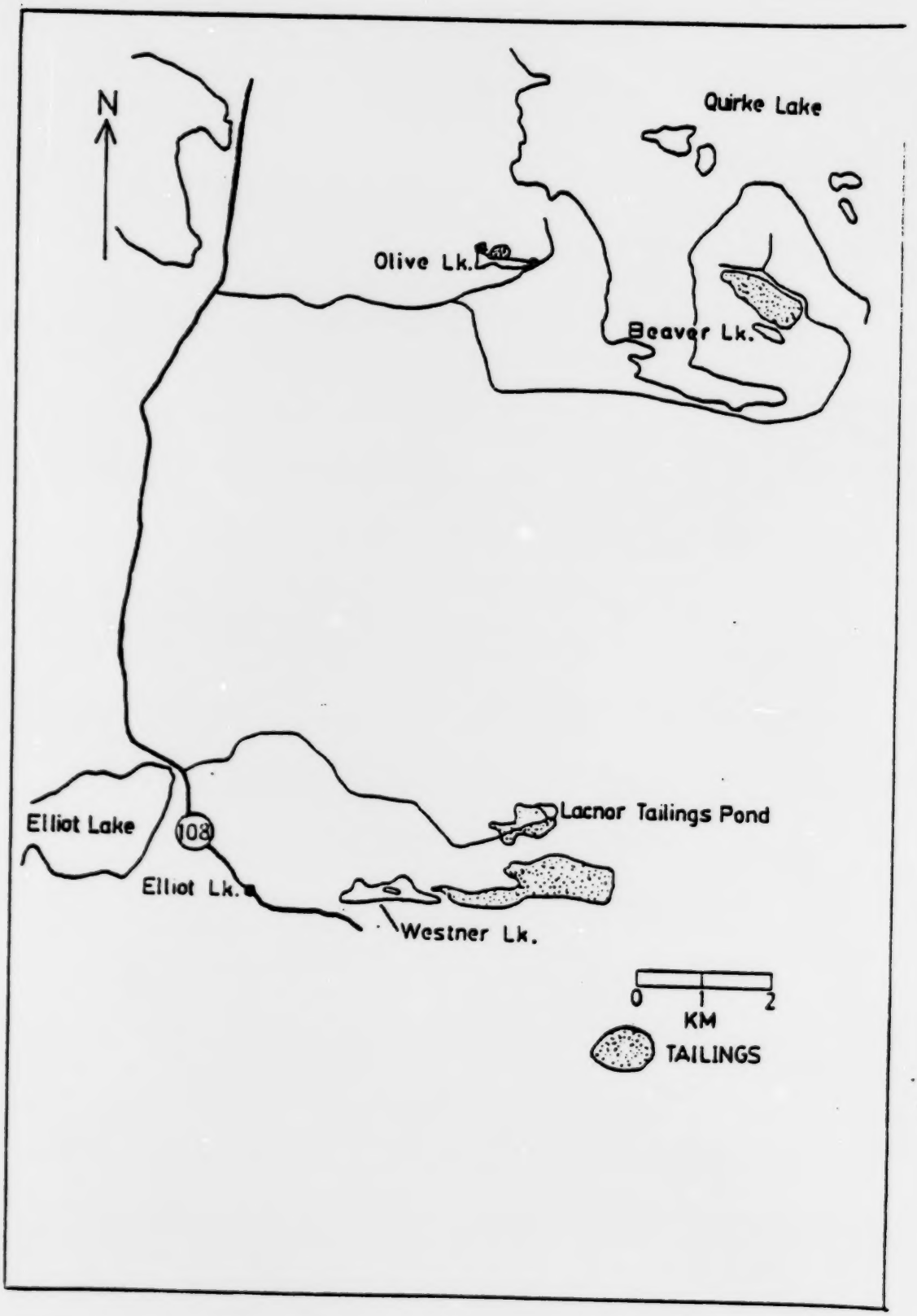

N
Wastewater Collection Ditch
Nordic Main Tailings
Westner Lk.
West Arm Tailings
Buckles Creek
North Nordic Lk.
Ryan Lk.
HWY 108
Nordic Effluent Treatment Plant
0 500 1000
metres

Figure 2. Locations of Beaver Lake, Lacnor Pond, Olive Lake and Westner Lake, and their associated tailings areas, near Elliot Lake, Ontario.


N
Quirke Lake
Olive Lk.
Beaver Lk.
Elliot Lake
108
Elliot Lk.
Lacnor Tailings Pond
Westner Lk.
0
1
2
KM
TAILINGS

leading edge of an underground seepage plume from the Nordic Main Tailings. Furthermore, this seepage plume had been under both hydrological and chemical investigation since 1979 [1, 2], and seemed likely to be receiving additional study for an indefinite period into the future.

Westner Lake similarly had several advantageous features for a research site. It was a small lake, and was known to be receiving both seepage water from the Nordic West Arm Tailings and clean water from the rest of its watershed. The seepages had been investigated previously in this case also [3]. Access was not difficult, but public entry was restricted by Rio Algom Ltd., the owner of the property. The cooperative attitude of this company was a critically significant consideration.

We compared the faunas of several tailings-associated lakes to determine whether they were each unique, or all relatively similar. Beaver Lake, Lacnor Pond and Olive Lake were chosen for their similarities to Westner Lake. They were all relatively small and accessible, and all had been acidified by tailings effluents. Also, Denison Mines and Rio Algom Ltd. had agreed to our entry on their properties.

To provide satisfactory data for the development of biogeochemical models, a research site would have to support both a representative fauna and a sufficient density of animals to permit cost-effective sampling and analysis. Consequently, the primary objective of our study was to

assess the distribution and abundance of any animal species we were able to quantitatively sample. Another major objective was to characterize the water chemistry of each site and to determine the extent of temporal and spatial variability in the more important parameters. For this aspect of the project we were grateful for the offer of analytical advice and assistance by personnel from the Mining Research Laboratories of CANMET at Elliot Lake.

MATERIALS AND METHODS

Study Areas

Buckles Creek

Three sampling stations were established in Buckles Creek, and marked by steel T-bars driven into the bank [Fig. 3]. Station U was about 1.2 km upstream from the seepage plume [2] and near the southeast perimeter of the Nordic Main Tailings Area. Station S was directly east of piezometer locations 6 and M13 [see Fig. 3 in Ref. 2]. This station was intended to be within the seepage plume's direct zone of influence, and a yellow/orange precipitate indicated that such was the case. Station D was approximately 0.3 km downstream from Station S. Although the yellow/orange precipitate was still evident here, available data [2] suggested that this site was well beyond the limit of the seepage plume. The T-bar at Station D was placed so that its upper end could be used as a reference point for monitoring water level, and possibly flow rate, in that portion of the creek.

Westner Lake

The sampling sites we employed in Westner Lake and the lake's physical features are shown in Figs. 4 & 5. A watershed-derived stream, and two visible seepage inflows from the Nordic West Arm Tailings [3], are also indicated. It was apparent that the water in Westner Lake was about 2 m above its original level. For this reason, the lake bottom

Figure 3. Locations of sampling stations U, S and D in Buckles Creek, near Elliot Lake, Ontario.

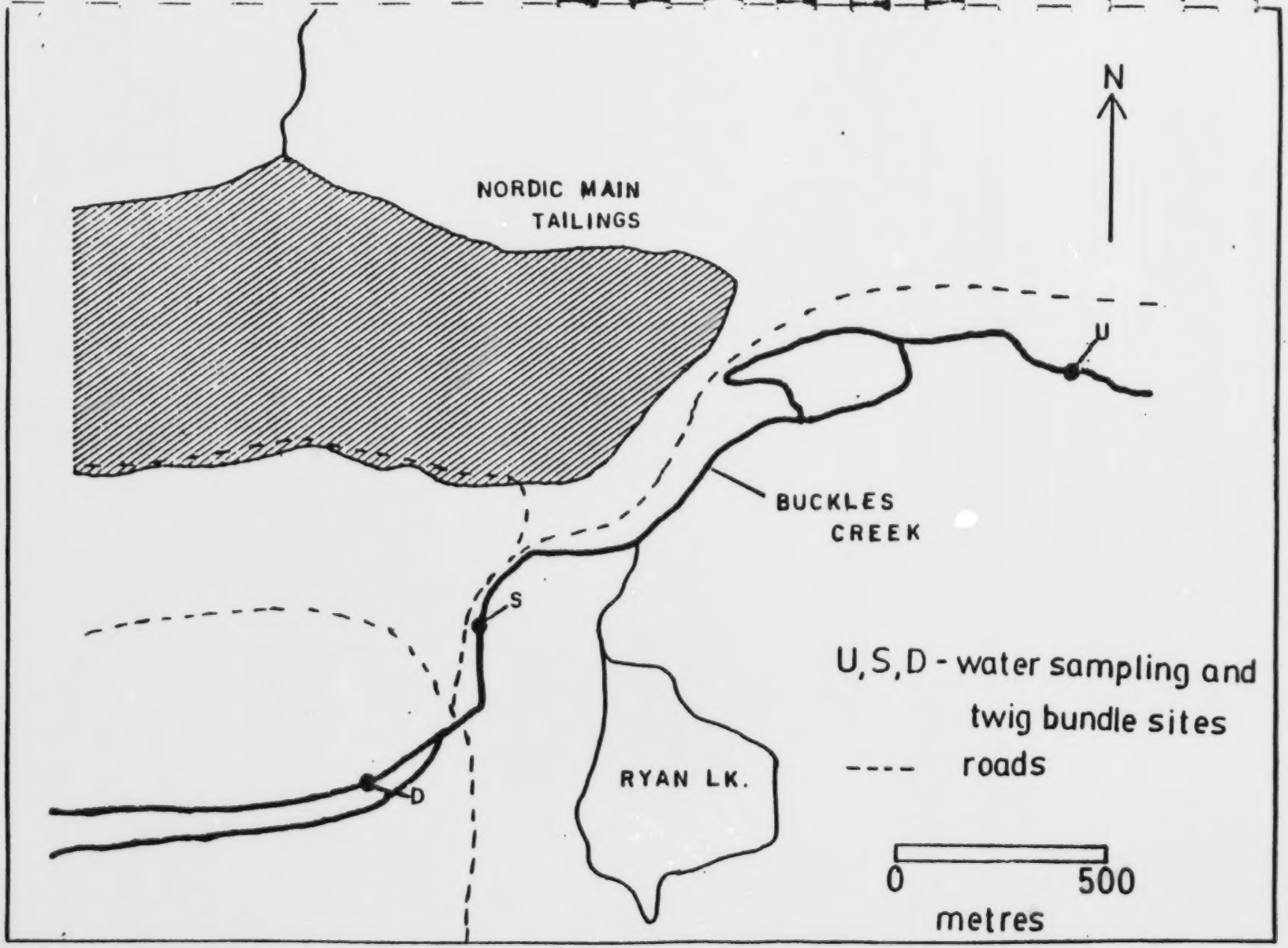

N
NORDIC MAIN
TAILINGS
U
BUCKLES
CREEK
S
D
RYAN LK.
U,S,D - water sampling and
twig bundle sites
roads
0
500
metres

Figure 4. Locations of sampling stations in Westner Lake, near Elliot Lake, Ontario.

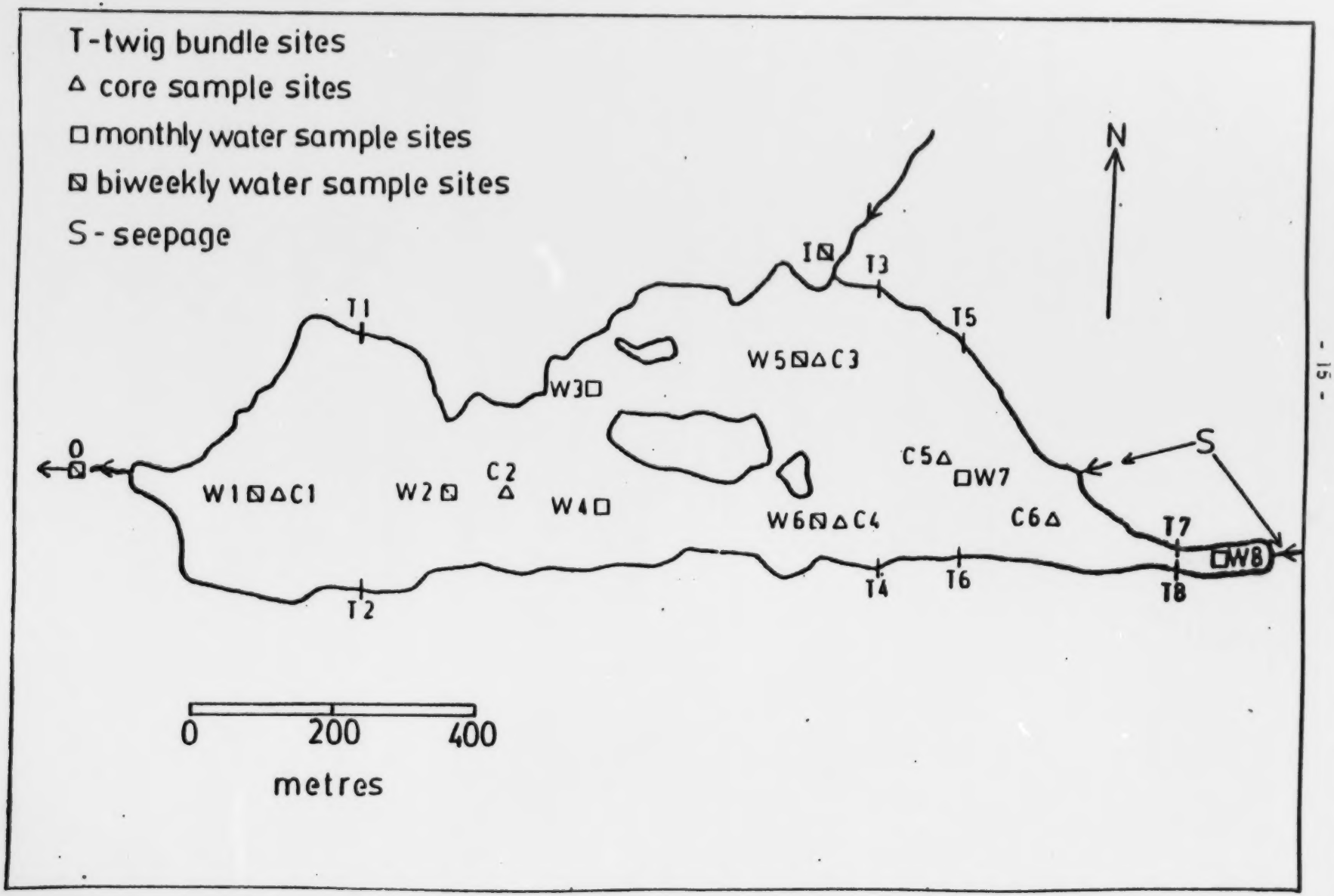
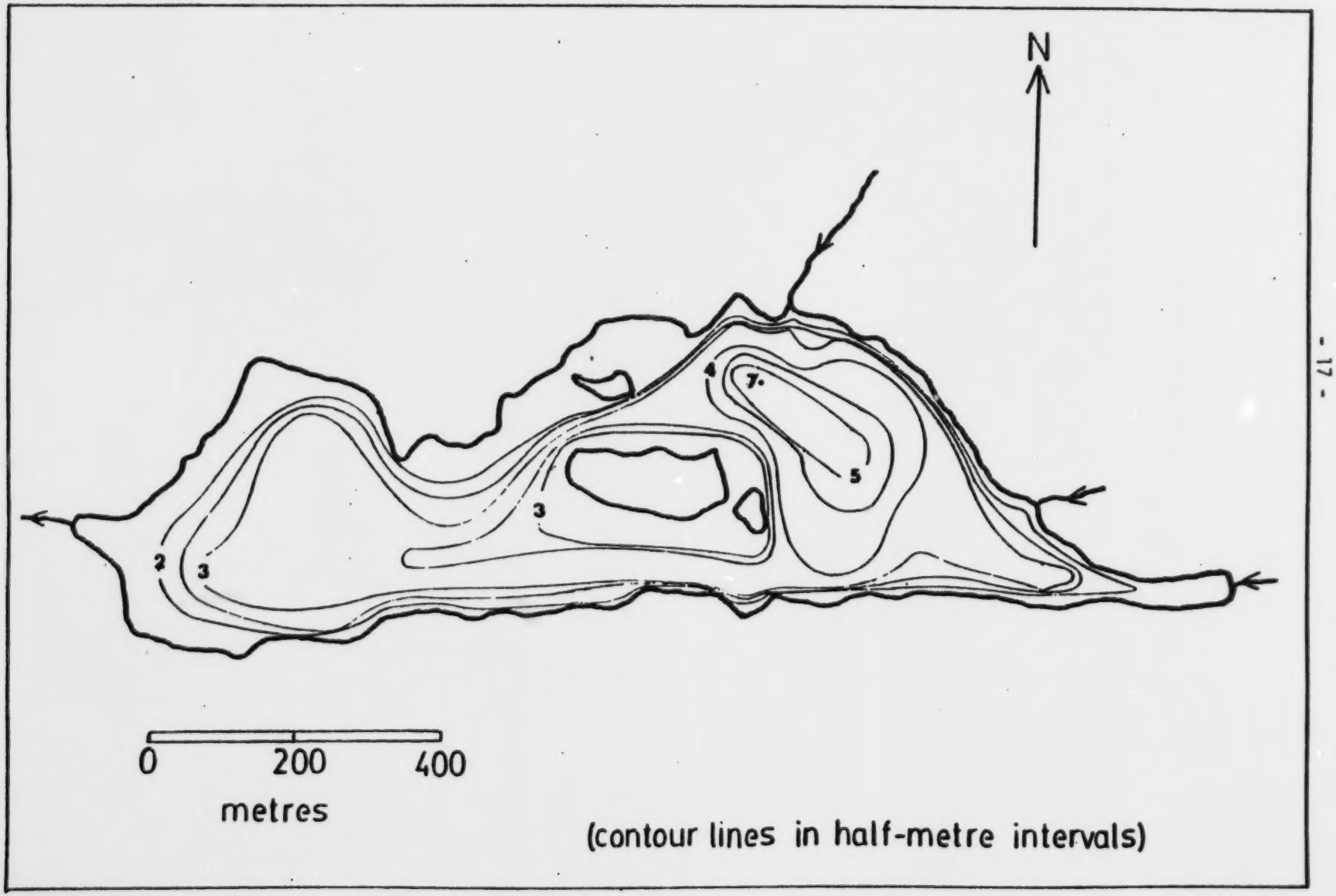

T-twig bundle sites
△ core sample sites
□ monthly water sample sites
▣ biweekly water sample sites
S - seepage
N
O
T1
T2
T3
T4
T5
T6
T7
T8
W1▣△C1
W2▣
C2
W3□
W4□
W5▣△C3
W6▣△C4
C5△
□W7
C6△
□W8
S
0
200
400
metres

Figure 5. Morphometry of Westner Lake, near Elliot Lake, Ontario.


N
4
7
5
3
2
3
0
200
400
metres
(contour lines in half-metre intervals)

in the shallow eastern bay did not consist of typical lake sediments. The littoral zone was unexpectedly rocky and essentially devoid of vegetation throughout the lake.

Beaver Lake

Beaver Lake was receiving treated effluents, runoff and dust from an adjacent, unvegetated, uranium tailings area. The littoral zone was generally stoney, and was completely devoid of vegetation. One mid-lake station [w] was used for all sets of water samples, while the fauna was sampled at a single station [b] in the littoral zone [Fig. 6].

Lacnor Pond

At Lacnor Pond, uranium tailings formed part of the shore and lake bottom; this situation allowed tailings runoff and seepage to enter the lake directly. Above the water level, the tailings surface was partially vegetated. The littoral zone was generally sandy and unvegetated. All water samples were obtained at Station [w], while the fauna was sampled at station [b] in the littoral zone [Fig. 7].

Olive Lake

As in Lacnor Pond, uranium tailings formed a part of the shore and lake bottom of Olive Lake, allowing seepage and runoff to enter the lake directly. Most of the tailings adjacent to this lake were well vegetated, but the littoral zone was unvegetated. One mid-lake site [w] was used for all sets of water samples, while the fauna was sampled at a single site [b] in the littoral zone [Fig. 8].

Figure 6. Locations of sampling stations in Beaver Lake, near Elliot Lake, Ontario.

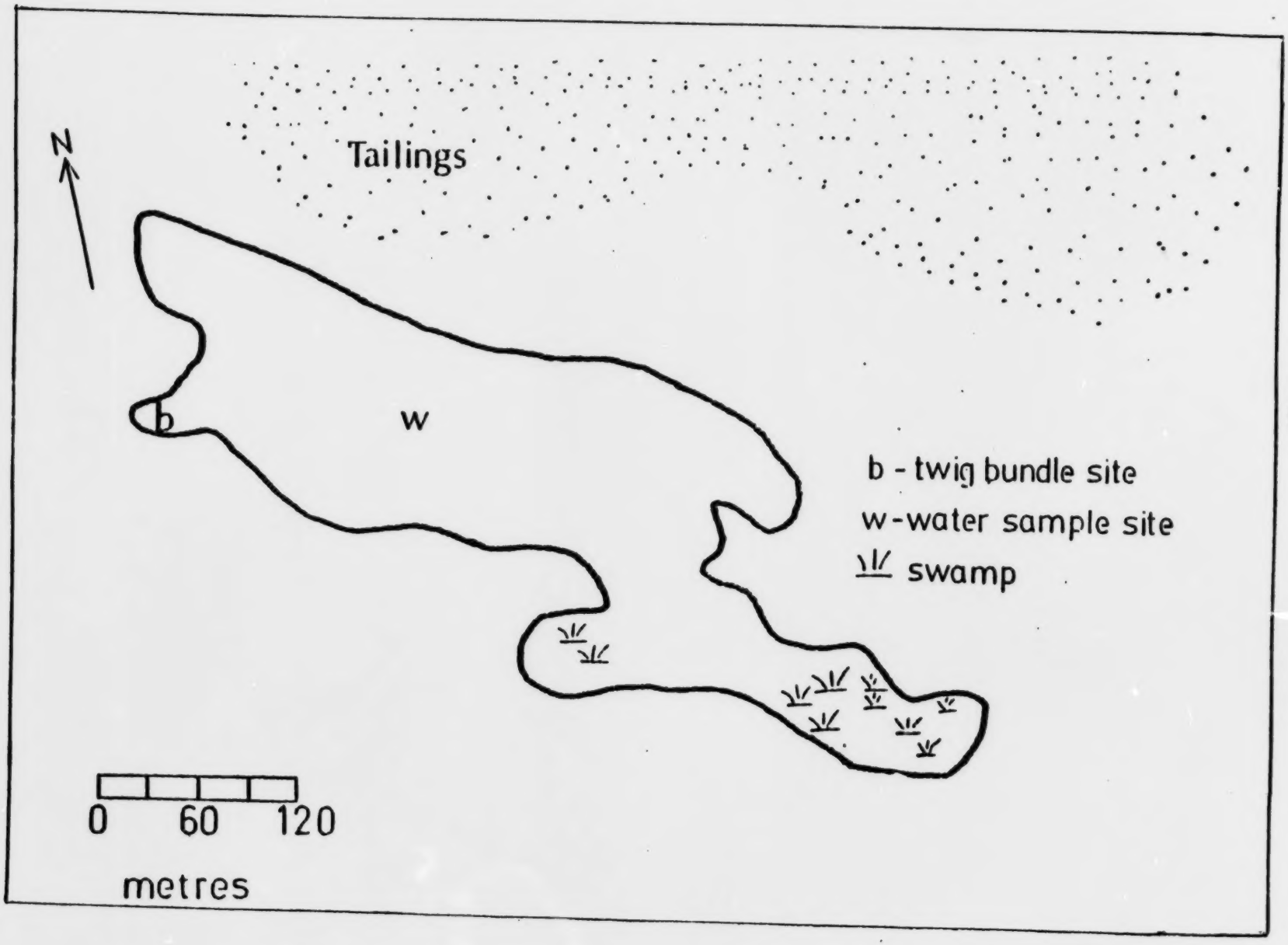

N
Tailings
b
w
b - twig bundle site
w-water sample site
swamp
0
60
120
metres

Figure 7. Locations of sampling stations in Lacnor Pond, near Elliot Lake, Ontario.

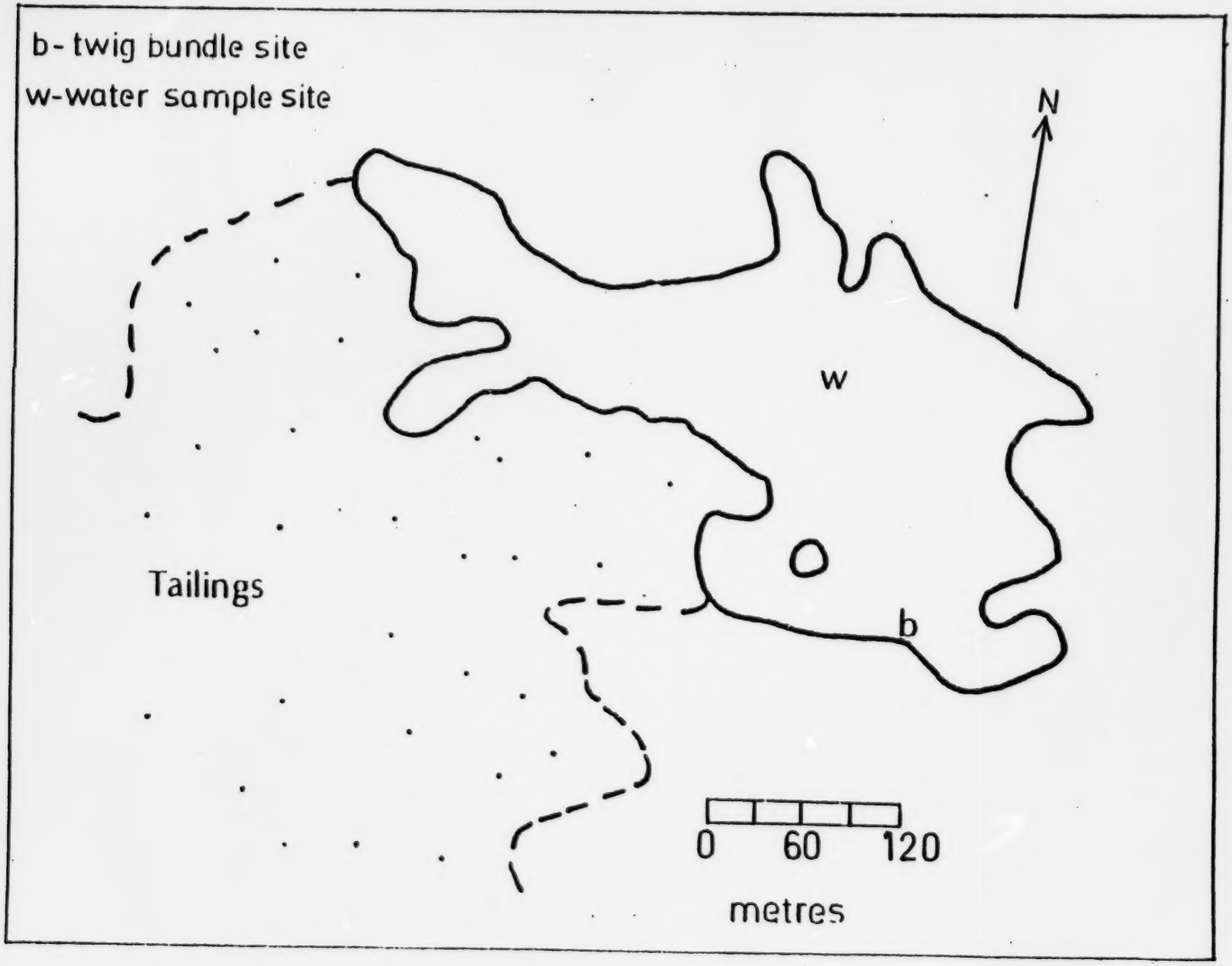
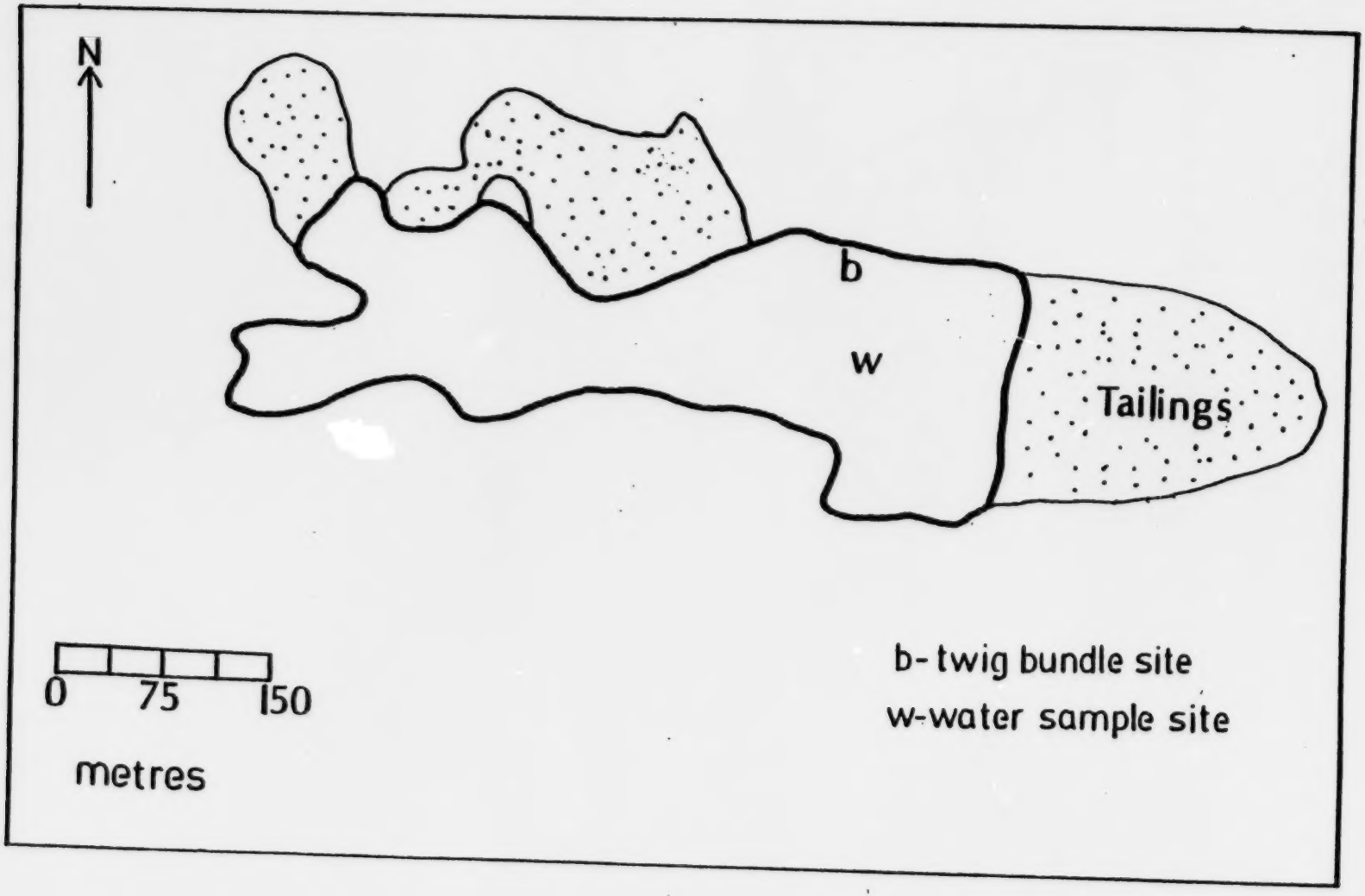

b - twig bundle site
w - water sample site
N
w
b
Tailings
0
60
120
metres

Figure 8. Locations of sampling stations in Olive Lake, near Elliot Lake, Ontario.


N
b
w
Tailings
0
75
150
metres
b- twig bundle site
w-water sample site

Twig Bundles

It was shown in Buckles Creek in 1983 [4] that small bundles of alder [*Alnus*] twigs were colonized within two weeks by a wide variety of aquatic invertebrates. Recovery of the twig bundles, and the animals living within/upon them, provided a simple, repeatable and quantitative technique for sampling habitats that were physically non-uniform or otherwise difficult to sample efficiently.

We originally intended to employ the twig bundle technique only in Buckles Creek, but since the littoral zone of Westner Lake was found to be mostly rocky and unvegetated, precluding the use of the Ekman grab, we decided to use twig bundles in the lakes as well.

All of our alder twigs [*Alnus crispa*] were obtained from a site in Montcreiff Township along the banks of Montcreiff Creek, 1.5 km north of Highway 144, and about 60 km northwest of Sudbury. After their leaves had been stripped away, the twigs were cut to 25 cm lengths and oven dried at 105C for 15 hours. The dried twigs were formed into tight bundles about 5 cm in diameter, containing about 40 twigs, and weighing 95-105 gm. Each bundle was held together by two small plastic cable ties. A length of cord was used to tie each twig bundle to an anchor [1.0 - 1.5 kg] made of mason's mortar.

Water Sampling

In 1984, water samples from Buckles Creek and Westner Lake were routinely collected in duplicate in cleaned 1 L

polyethylene bottles that had been acid-washed and rinsed with distilled-deionized water. In Buckles Creek, samples were taken directly into the bottles at about 10 cm beneath the water's surface. In Westner Lake, a previously cleaned and acid-washed, 5 L acrylic plastic Van Dorn bottle was employed to obtain water from various levels in the water column. The two sample bottles were then immediately filled from the Van Dorn bottle. In all cases, one sample of each pair was used for pH and conductivity determinations as soon as possible after collection. The second sample was acidified at collection with 5.0 ml of analytical grade nitric acid, and used for all other chemical analyses. With the assistance of the CANMET laboratory in Elliot Lake, concentrations of sulfate, calcium, magnesium, aluminium, iron, manganese, lead, uranium and 226-radium were determined in virtually all samples. Silica and thorium were analysed initially in a few samples from both Buckles Creek and Westner Lake, but it did not seem worthwhile to carry this forward.

In Buckles Creek, water samples were collected at Stations U, S and D on the following dates in 1984: August 30, September 13, September 27, October 26 and November 8. On August 21, pH was determined on site.

In 1984, the waters of Westner Lake were sampled as indicated in Table 1 and Fig.4 .

In addition to the above, supplementary water samples were obtained from the apparent seepage zones at both Buckles Creek and Westner Lake. In each case, pH was

Table 1. Water sampling program for Westner Lake (1984).

SITES	DATES				
	August 31	September 12	October 4	October 25	November 8
W1	⊛	⊛	⊛	⊛	⊛
W2	⊛	⊛	⊛	⊛	⊛
W3	-	⊛	-	⊛	-
W4	-	⊛	-	⊛	-
W5	⊛	⊛	⊛	⊛	⊛
W6	⊛	⊛	⊛	⊛	⊛
W7	-	⊛	-	⊛	-
W8	*	*	-	*	-
I	-	*	*	-	-
O	*	*	*	*	*

⊛ Duplicate sampling at 0.1 and 2m beneath the surface.

● Duplicate sampling at 0.1, 2, 4 and 6m beneath the surface.

* Duplicate sampling at 0.1m beneath the surface.

- No samples collected.

recorded immediately. The creek was sampled on October 26 at 20 m intervals both upstream [14 locations] and downstream [4 locations] from Station S. At the eastern end of Westner Lake, seepage-water emerged from a long sloping bank, and it could be sampled conveniently prior to its reaching the shoreline. Duplicate samples were obtained on October 4 and 26 at three elevations; one was just above the surface of the lake, one was at the highest point of seepage emergence, and one was at an intermediate level.

After pH was recorded, 18 supplementary samples from Buckles Creek, and three from seepage areas at Westner Lake, were stored at room temperature in the laboratory until December 20, 1984. Water pH was monitored, and evaporated water was replaced with distilled water at approximately weekly intervals. In addition, replicate samples of the West Arm [Westner Lake] seepage were acidified and analysed similarly to lake-water samples.

In Westner Lake, submersible probes were used at Stations W1 - W8 to determine temperature and dissolved oxygen profiles existing on August 31 and September 12 1984.

In 1985, water samples were collected from Westner Lake, Beaver Lake, Lacnor Pond and Olive Lake on both June 25 and July 31 [Table 2; Fig.'s 4, 6, 7, and 8]. In Westner Lake, samples were collected at Station W5. The Van Dorn bottle was not used in 1985. Instead, the open end of an acid-washed polyethylene tube was weighted and lowered to each required sampling point. Water could then be drawn up and through a 0.6 u filter into a partially evacuated,

Table 2. Water sampling locations in four tailings-influenced lakes sampled from surface to bottom on June 25 and July 31, 1985

	LAKES			
	BEAVER	LACNOR	OLIVE	WESTNER
STATIONS	W	W	W	W5
DEPTHS (m)	0.1	0.1	0.1	0.1
	-	-	-	-
	-	1.8	1.5	1.8
	2.7	3.0*	3.0	-
	-	-	-	3.6
	-	4.4	4.6	-
	5.5	-	-----	5.5
	-	6.1**		-----
	7.9	-----		
	-----			

* July 31 only

** June 25 only

----- - bottom

acid-washed, polycarbonate plastic flask. After the first 1.5 L thus obtained had been discarded, replicate water samples were added to three polyethylene bottles, which had been cleaned as in 1984. One sample from each site was acidified with analytical grade nitric acid, and subsequently analysed for aluminium, iron, manganese and 226-radium. The second sample was placed in an ice-chest, unacidified, and analysed as soon as possible for pH, conductivity and acidity [titration to pH 7]. The third sample, also unacidified and chilled, was analysed within a few days for calcium, magnesium and sulfate concentrations.

Lake Sediments

A total of 15 sediment cores were obtained from six different locations in Westner Lake, on October 4, 1984 [Fig. 4; C1 - C6]. Each core contained 10-20 cm of undisturbed sediments, and at least 10 cm of overlying water, sealed inside a transparent polycarbonate plastic tube, 5 cm in diameter.

In the laboratory, the upper end of each tube was unsealed, and both pH and Eh [platinum] electrodes were inserted, side by side. When pH and electrode potential had been determined at the sediment surface, the electrodes were temporarily withdrawn so that a 4 cm layer of sediment could be aspirated into a small polyethylene bag and saved [frozen] for further analysis. The electrodes were then rinsed with distilled water and re-inserted into the sediments remaining in the core tube. By repeating this

sequence, pH and electrode potential were determined at successively lower positions in the sediment, and the core was divided into a vertically ordered set of equal-volume sub-samples. Where a surface crust was encountered, it was removed to the plastic bag using forceps rather than by aspiration. At a later date, sub-samples were thawed and prepared for aluminum, iron, manganese, lead, zinc and 226-radium analysis.

Faunal Studies

Buckles Creek

Standard minnow nets and dip nets were employed on September 13, 1984, in an effort to capture fish, amphibians and crayfish at Stations U, S and D. We also attempted to locate specimens by sight so that they could be driven into nets placed across the creek.

Ten twig bundles were installed at each of Stations U, S and D on August 21, 1984. On September 27, 1984, each twig bundle was placed individually in a plastic bag and removed from the creek. Pin-holes in the bags permitted excess water to drain away without allowing specimens to escape. The bags were transported immediately to the laboratory where they were stored in a freezer. To recover the fauna thus collected, twig bundles were allowed to thaw in a large trays and the cable ties were cut. Specimens were then obtained by rinsing and sweeping each twig with a small soft brush. The twigs were returned to their bags and re-frozen. Specimens were picked from the trays under a

stereoscopic microscope, and preserved in bottles containing 70% ethanol. Later, the specimens from each twig bundle were sorted taxonomically as far as possible, and counted.

A second set of 10 twig bundles was installed at each of the same three sites in Buckles Creek on September 27, 1984. These twig bundles were removed from the creek to the freezer on November 8, 1984. They were subsequently thawed and examined for specimens in the same way as the first set.

Westner Lake

On August 30, 1984, 7 groups of 5 twig bundles each were placed at 7 locations in the littoral zone of Westner Lake [Fig. 4; T1-T6 and T8]. These were collected in plastic bags, frozen, and replaced by a second set of twig bundles on October 4, 1984. The second set was collected and stored similarly on November 8, 1984. All of these twig bundles and their contents were subsequently treated in the same manner as described above for Buckles Creek.

Zooplankton sampling was conducted in Westner Lake on August 31, October 4, and October 12, 1984. On each date two vertical hauls of a large [mouth diameter 50 cm] plankton net were performed in both the eastern and western basins of the lake [Fig. 4; W2 and W5]. Twice on the latter date, the net was also hauled horizontally for 25 m at 1-2 m below the surface.

To collect benthic invertebrates living beyond the littoral zone, Ekman grab samples were obtained at 56 sites distributed along four transects [Fig. 4; T1-T2, T3-T4,

T5-T6, T7-T8]. The sediments so obtained were wet-seived, and all specimens observed on the screens were preserved in 70% ethanol. The finest screen had openings 1.5 mm wide.

In 1985, a set of ten twig bundles was placed at a single site in Westner Lake on May 29 [Fig. 4; T2]; a second set of ten was placed at the same site on June 25. The first set was collected into plastic bags and removed to the freezer on June 25, while the second set was collected and preserved in the same manner on July 31. Specimens were subsequently removed from the twig bundles and stored and analysed as in 1984.

Beaver Lake, Lacnor Pond and Olive Lake

Twig bundles were also employed in each of Beaver, Lacnor Pond and Olive Lakes in 1985. As in Westner Lake, sets of 10 were installed on May 29 and June 25. The first sets were recovered on June 25, and the second set on July 31. The twig bundles and their faunas were treated and analysed in the same manner as those from Westner Lake.

226-Radium in Twigs

After the fauna had been removed from the twig bundles set out in 1984, several samples of unused [control] twigs and twigs that had been exposed to the waters of Buckles Creek and Westner Lake were prepared for 226-radium analysis. The bark was removed from each twig so that the wood and the bark could be analysed separately.

RESULTS

Buckles Creek

Water Quality

The water level at Station D in Buckles Creek rose steadily from mid August to mid October and then dropped precipitously in late October [Fig. 9]. Unfortunately, flow rates were not well correlated with water levels; during September beavers constructed a dam downstream from Station D, and then the dam was breached in late October.

Table 3 summarizes water quality observations recorded for Stations U, S and D in 1984. The pH was always highest at Station U, but pH usually dropped less than one pH unit between U and D. Lead and uranium concentrations were always below detection limits [0.1 and 0.8 mg/L respectively] at all three sites. In samples collected from Station D on August 30 and September 13, 1984, 226-radium was recorded at 2.6 and 0.6 pCi/L, but this element was below our 0.3 pCi/L detection limit in all other samples. All other measured parameters increased significantly from Station U to Station S, but generally they did not change significantly from Station S to Station D.

Beginning about 200 m upstream from Station S, an orange-yellow precipitate appeared in Buckles Creek. From this point downstream to Station D, and for an undetermined distance beyond, it formed an obvious coating on all objects in contact with the water.

Figure 9. Water level fluctuations in Buckles Creek from mid August to mid November 1984.

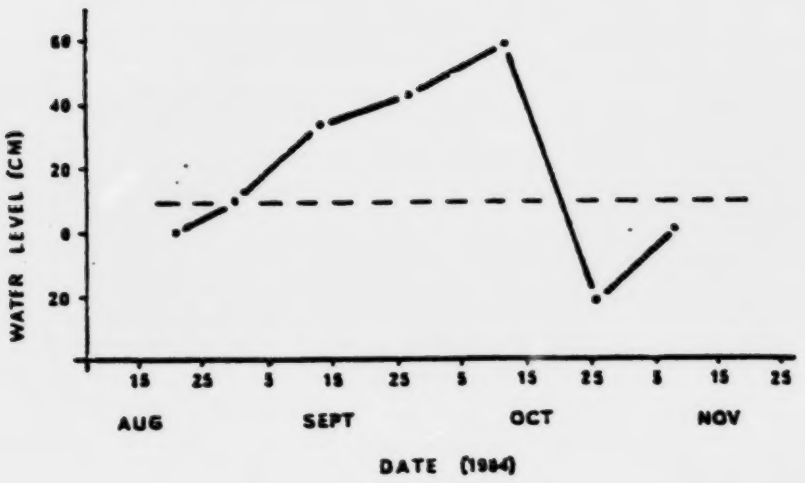


Table 3. Variation in eleven water quality parameters at three locations in Buckles Creek, near Elliot Lake, Ontario, observed during late summer and fall 1984. Seepage from the North Nordic Tailings Area was apparently entering the creek at site S. Site U was about 1.2 km upstream, and site D about 0.3 km downstream, from site S. Except where indicated otherwise, concentrations are expressed in $mg.L^{-1}$.

PARAMETER	DATE	SITE		
		U	S	D
Field pH	Aug. 21	6.8	6.0	5.6
	Aug. 30	6.7	6.2	5.7
	Sept. 13	6.5	6.2	6.2
	Sept. 27	6.4	6.2	6.2
	Oct. 26	6.5	6.4	6.3
	Nov. 8	6.3	6.1	6.2
	Median	6.5	6.2	6.2
Conductivity ($\mu S.\ cm^{-1}$)	Aug. 30	48	320	320
	Sept. 13	46	60	100
	Sept. 27	44	90	90
	Oct. 12	49	110	150
	Oct. 26	58	180	185
	Nov. 8	89	140	150
	Mean	56	150	165
Sulfate	Aug. 30	13	135	135
	Sept. 13	13	22	28
	Sept. 27	9	36	26
	Oct. 12	11	51	54
	Oct. 26	10	61	45
	Nov. 8	11	28	32
	Mean	11	56	53

continued....

Table 3. continued....

PARAMETER	DATE	SITE		
		U	S	D
Calcium	Aug. 30	6	28	34
	Sept. 13	5	8	10
	Sept. 27	5	9	9
	Oct. 12	5	11	14
	Oct. 26	4	11	14
	Nov. 8	4	7	9
	Mean	5	12	15
Magnesium	Aug. 30	1.0	13.0	11.5
	Sept. 13	1.0	1.0	2.5
	Sept. 27	1.0	2.5	3.0
	Oct. 12	1.0	4.5	5.5
	Oct. 26	0.9	5.0	5.0
	Nov. 8	0.9	2.5	3.0
	Mean	1.0	4.8	5.1
Aluminum	Aug. 30	0.10	0.22	0.53
	Sept. 13	0.07	0.12	0.19
	Sept. 27	0.07	0.09	<d.l.
	Oct. 12	<d.l.	0.10	0.17
	Oct. 26	<d.l.	0.22	0.19
	Nov. 8	<d.l.	<d.l.	0.14
	Median	d.l.	0.11	0.18
Iron	Aug. 30	1.0	13.0	10.5
	Sept. 13	1.0	2.5	2.2
	Sept. 27	0.5	3.5	2.5
	Oct. 12	1.0	4.0	3.5
	Oct. 26	0.5	6.5	5.0
	Nov. 8	0.5	2.5	2.5
	Mean	0.8	5.3	4.4

continued....

Table 3. continued....

PARAMETER	DATE	SITE		
		U	S	D
Manganese	Aug. 30	0.24	0.88	0.94
	Sept. 13	0.15	0.13	0.16
	Sept. 27	0.11	0.15	0.14
	Oct. 12	0.15	0.33	0.41
	Oct. 26	0.10	0.29	0.29
	Nov. 8	0.07	0.14	0.18
	Mean	0.14	0.32	0.35
Lead	All Dates	<d.l.	<d.l.	<d.l.
Uranium	All Dates	<d.l.	<d.l.	<d.l.
226-Radium (pCi/L)	Aug. 30	<d.l.	<d.l.	2.6
	Sept. 13	<d.l.	<d.l.	0.6
	All Other Dates	<d.l.	<d.l.	<d.l.

<d.l. - less than detection limit

On October 26, 1984, there was no significant variation in pH either upstream or downstream near Station S [Fig. 10A]. However, after five days or more of storage, water samples from this area showed two obvious acidifications; one of these was associated with Station S itself, and the other with a point about 60 m upstream from Station S [Fig. 10B & C]. By 10 days of storage, all samples that had been collected from points within 120 m upstream from Station S had begun to exhibit an orange/yellow staining. None of the samples obtained 140 m or more upstream from Station S showed such coloration at this time, but they all had developed at least a faint yellow color by 55 days.

Fauna

No fish or amphibians were collected at any of the three sampling sites in Buckles Creek. Since both had been observed by the author near Station U in 1983, and frogs had also been observed at Station D, this was unexpected.

Most of the aquatic macro-invertebrates obtained from twig bundles at Stations U, S and D were insects [Tables 4 and 5]. This fauna was heavily dominated by the larvae of chironomid flies [known as midges or bloodworms], but their abundance varied considerably among sites. Excepting the genus *Chironomus*, these larvae were very small [< 8 mm] and could not be separated fully on the basis of external features. Specimens provisionally identified as *Phaenopsectra*, *Sergentia* and *Polypedilum*, and an unidentified member of the Tanypodini were among the latter

Figure 10. Variation in pH among water samples collected near site S in Buckles Creek.

A. At time of collection, October 26, 1984.

B. After storage for five days.

C. After storage for 55 days.

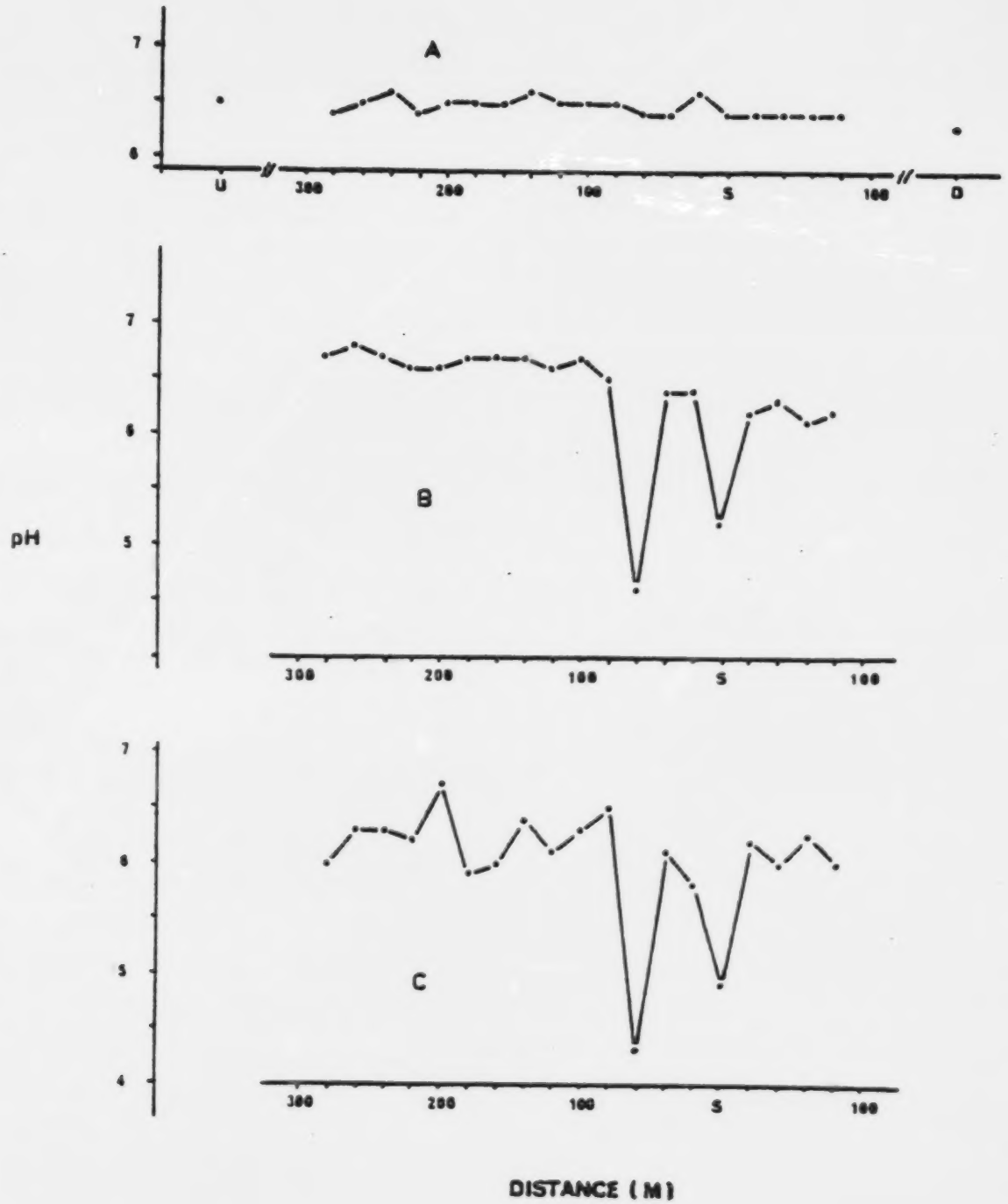

A
B
C
pH
7
6
5
4
U
300
200
100
S
D
DISTANCE (M)

Table 4. Specimen counts for macro-invertebrates (Families) inhabiting twig bundles [20 / Station] from Buckles Creek [1984].

TAXA	SAMPLING STATIONS		
	U	S	D
INSECTS			
FLY LARVAE [Diptera]			
Blood Worms - Chironomidae larvae	2230	1020	3010
Black Flies - Simulidae larvae	0	59	0
Crane Flies - Tipulidae larvae	4	0	1
Biting Midges - Heleidae larvae	0	2	0
Mayfly Nymphs [Ephemeroptera]			
Leptophlebiidae	37	23	1
Caenidae	1	2	0
Caddisfly Larvae [Trichoptera]			
Hydropsychidae	10	9	0
Limnephilidae	1	12	1
Phryganeidae	2	0	3
Polycentropidae	2	0	1
Beetle Larvae [Coleoptera]			
Dytiscidae	2	6	19
Alderfly Larvae [Megaloptera]			
Sialidae	0	3	8
Dragonfly/Damselfly Nymphs [Odonata]			
Anisoptera	0	1	0
Zygoptera	0	1	0
Giant Water Bugs [Hemiptera]			
Belastomatidae	0	1	0

Table 4. Cont'd.

	U	S	D
CRUSTACEANS			
Seed Shrimps [Ostracoda]			
Candonidae	81	4	24
Scuds [Amphipoda]			
Talitridae	1	0	0
ARACHNIDS			
Water Mites [Acarina]			
Oribatidae	6	0	4
Hydracarina	3	8	4
SEGMENTED WORMS [Oligochaeta]			
Haplotaxidae	1	6	0
MOLLUSCS			
Clams [Bivalvia]			
Sphaeridae	3	0	2

Table 5. Genera of aquatic invertebrates identified in twig bundles recovered from Buckles Creek [1984].

FAMILIES*	GENERA
Chironomidae	*Chironomus* *Phaenospectra* or *Sergentia* *Polypedilum* *Sergentia*
Tipulidae	*Tipula* [3 species]
Heleidae	*Palpomyia* group
Leptophlebiidae	*Leptophlebia* *Paraleptophlebia*
Caenidae	*Caenis*
Phryganeidae	*Ptilostomis*
Polycentropidae	*Polycentropus*
Dytiscidae	*Agabus/Ilybius* *Hydroporus*
Sialidae	*Sialis*
Belastomatidae	*Lethocerus*
Candonidae	*Candona*
Talitridae	*Hyalella azteca*

* In sequence as listed in Table 4.

group. Other genera may have been present also, but time available did not permit many specimens to be classified beyond the family level, because it would have been necessary to examine their dissected heads individually on microscope slides.

Westner Lake

Water Quality

Table 6 summarizes water quality in Westner Lake and its outlet stream for the period August 31 to November 8, 1984. Data from throughout the lake were pooled for each sampling date because they exhibited little variation either among vertical positions in the water column or among the different sampling stations. At station 0 in the outlet stream [Fig. 4], water quality was similar to that in lake.

Westner Lake was found to be more than 90% saturated with oxygen at all stations and at all depths sampled. Mid day dissolved oxygen concentrations ranged from 8.5 to 10.7 mg/L for August 31 and September 12, 1984.

The chemical characteristics of the visible inflows to Westner Lake are shown in Table 7. Seepage entering from the Nordic West Arm Tailings Area was undoubtedly best represented by data from the lowest sampling point, just above the shoreline, but there was little change in water chemistry between the middle and lower sampling points.

When seepage water was stored in the laboratory, its pH began to fall within a few days [Table 8]. Acidification continued for about 1.5 months in all three samples, but

Table 6. Summary of water quality data for Westner Lake and its outlet stream, near Elliot Lake, Ontario, through late summer and fall 1984. Numbers in parentheses refer to the outlet stream. The range is shown for lake pH. The mean ± S.E. is given for other parameters, as appropriate. Sulfate and metal concentrations are in $mg.L^{-1}$.

PARAMETER	AUGUST 31	SEPTEMBER 12	OCTOBER 4	OCTOBER 26	NOVEMBER 8
Number of Sites Sampled	11 (1)	14 (1)	10 (1)	16 (1)	8 (1)
Field pH	3.1 - 3.3 (3.8)	3.1 - 3.2 (3.2)	3.1 (3.5)	3.0 - 3.2 (3.1)	3.1 - 3.2 (3.2)
Conductivity ($\mu S.cm^{-1}$)	580 ± 15 (410)	610 ± 5 (460)	540 ± 15 (430)	645 ± 10 (660)	600 ± 10 (600)
Sulfate	200 ± 8 (180)	195 ± 3 (170)	210 ± 3 (180)	190 ± 3 (200)	180 ± 3 (175)
Calcium	33 ± 0.5 (32)	33 ± 0.1 (32)	33 ± 0.2 (34)	31 ± 0.3 (30)	30 ± 0.2 (30)
Magnesium	9.6 ± 0.1 (9.8)	9.7 ± 0.1 (9.5)	9.7 ± 0.1 (10.2)	10.0 ± 0.04 (9.9)	9.2 ± 0.04 (9.2)
Aluminum	5.0 ± 0.08 (3.6)	4.9 ± 0.02 (4.8)	4.8 ± 0.01 (5.2)	4.9 ± 0.04 (5.3)	4.4 ± 0.02 (4.6)
Iron	5.1 ± 0.9	4.2 ± 0.2 (2.69)	4.0 ± 0.04	4.2 ± 0.04 (2.64)	4.0 ± 0.04 (3.14)
Manganese	0.68 ±0.008	0.69 ±0.002 (0.9)	0.68 ±0.003 (1.7)	0.76 ±0.008 (0.9)	0.67 ±0.004 (0.7)
^{226}Radium ($pCi.L^{-1}$)	2.3 ± 0.2 (1.0)	2.4 ± 0.2 (1.6)	2.3 ± 0.3 (1.6)	2.0 ± 0.3 (1.8)	1.7 ± 0.3 (1.8)

Table 7. Water quality characteristic of watershed-derived creek water and tailings-derived seepage water entering Westner Lake, near Elliot Lake, Ontario, during the fall of 1984. The seepage was sampled at three levels down the bank from which it was emerging. (Flow volumes from the creek and from the visible seepages appeared to be of the same order of magnitude, and both were small.) Sulfate, metal and uranium concentrations are expressed as $mg.L^{-1}$.

	WATERSHED-DERIVED	TAILINGS-DERIVED SEEPAGE WATER		
PARAMETER	CREEK WATER	UPPER	MIDDLE	LOWER
No. samples	1 - 3	1	2	2
Field pH	6.2 - 6.6	3.3	3.0	2.9
Conductivity ($\mu S.cm^{-1}$)	51	1,970	3,750	3,800
Sulfate	17	2,630	3,880	4,160
Calcium	5.4	305	295	315
Magnesium	1.2	35	80	90
Aluminum	<0.1	80	105	110
Iron	<0.1	470	770	820
Manganese	<0.1	1.7	3.9	4.0
Lead	<0.1	<0.1	0.9	0.9
Uranium	<0.8	2.2	3.8	4.0
^{226}Radium ($pCi.L^{-1}$)	<0.3	15.8	9.5	9.5

Table 8. Temporal pH changes in tailings-derived seepage collected on October 4, 1984, at the eastern end of Westner Lake, near Elliot Lake, Ontario.

SAMPLE pH	DATE OCT. 4	OCT. 5	OCT. 8	OCT. 9	OCT. 15	OCT. 31	DEC. 20
Maximum	3.3	3.2	2.8	2.7	2.6	2.4	2.3
Minimum	2.8	2.8	2.6	2.5	2.4	2.4	2.2

most of the pH change had occurred within the first month. Overall, pH declined about 1 pH unit during storage.

Table 9 compares the chemical analyses of surface waters from Westner, Beaver, Lac Nor and Olive Lakes [1985]. These data were of greatest interest because they represent the zone from which fauna was obtained using twig bundles, but in Westner Lake water quality was not significantly different between the surface and the rest of the water column. In 1985, the water chemistry of Westner lake was similar in all respects to that recorded in 1984.

Sediment Quality

The whole lake bottom was apparently well oxygenated. Electrode potentials were positive through at least the upper 2 cm of all 15 sediment cores, and orange/yellow granules or concretions, presumably consisting of ferric hydroxide and jarosite-like minerals [5], were present in the upper 2-10 cm of each core. A distinct orange crust formed the sediment surface throughout the eastern third of the lake, and also coated tree branches lying at the bottom. In the eastern arm of the lake the crust was dense enough to impede the core sampler, but three short cores were eventually obtained from this area. The sediment surface was near pH 3.5 in most cores. Vertical pH profiles were also similar among most cores, including those with a crustose surface, and generally pH increased slowly with increasing distance below the sediment-water interface. Median pH values were about 0.5 pH units lower in the

Table 9. Surface water analyses for four tailings-influenced lakes near Elliot Lake, Ontario, sampled on June 25 (upper values) and July 31 (lower values), 1985.

PARAMETERS	BEAVER LAKE	LACNOR POND	OLIVE LAKE	WESTNER LAKE
Conductivity ($\mu S.cm^{-1}$)	4,000	1,570	1,450	565
	5,800	1,810	1,590	520
Acidity ($mg.L^{-1} CaCo_3$)	2,770	320	225	65
	3,370	415	230	60
pH	2.3	2.6	2.7	3.0
	2.5	2.5	2.8	3.2
Sulphate*	4,880	680	595	215
	5,130	910	570	190
Calcium*	204	86	91	65
	187	85	91	30
Magnesium*	37	20	16	8
	46	29	21	11
Aluminum*	130	8.7	8.0	4.0
	86	11.3	9.1	4.1
Iron*	760	72	33	1.6
	1,250	95	31	1.6
Manganese*	6.0	1.2	1.4	0.5
	7.1	1.8	1.5	0.6
226 Radium ($pCi.L^{-1}$)	**	20.8	32.5	3.4
	**	22.7	31.0	3.8

* $mg.L^{-1}$

** Undetermined

western than the eastern half of the lake [Fig. 11]. Also, three of four cores that exhibited comparatively high pH came from the eastern half of the lake.

The chemical analyses of sediment cores are summarized in Table 10. Except in a single core that had a crust over the entire sediment surface, there were no major differences among cores. Generally, the upper layers of sediment appeared to be accumulating iron, 226-radium and lead, although the crust itself was low in 226-radium. Concentrations of aluminum, manganese and zinc were lower in the surficial than the deeper strata of sediments.

Fauna

The aquatic fauna obtained from twig bundles in Westner Lake included several taxa of arthropods [Table 11]. Most numerous was a minute oribatid mite, provisionally identified as *Hydrozetes*; in 1984, virtually every twig bundle contained 50-100 specimens. Two types of chironomid larvae [midge larvae or blood worms] were collected. Although less numerous than the mites, they were much larger, and thus they accounted for most of the biomass in our samples. The largest and commonest blood worms were members of the Subfamily Chironomini in the genus *Chironomus*; a small number of *Chironomus* pupae were also collected. The other chironomid was from the Orthocladini, and apparently belonged to the genus *Limnophyes*.

In 1984, a few specimens of at least three larval trichopterans [caddis flies] were found in the twig bundles

Figure 11. Sediment pH recorded from 15 sediment cores collected in Westner Lake on October 4, 1984.

a. Minimum values observed.

b. Medians among 5 cores from western basin.

c. Medians among 10 cores from eastern basin.

d. Maximum values observed.

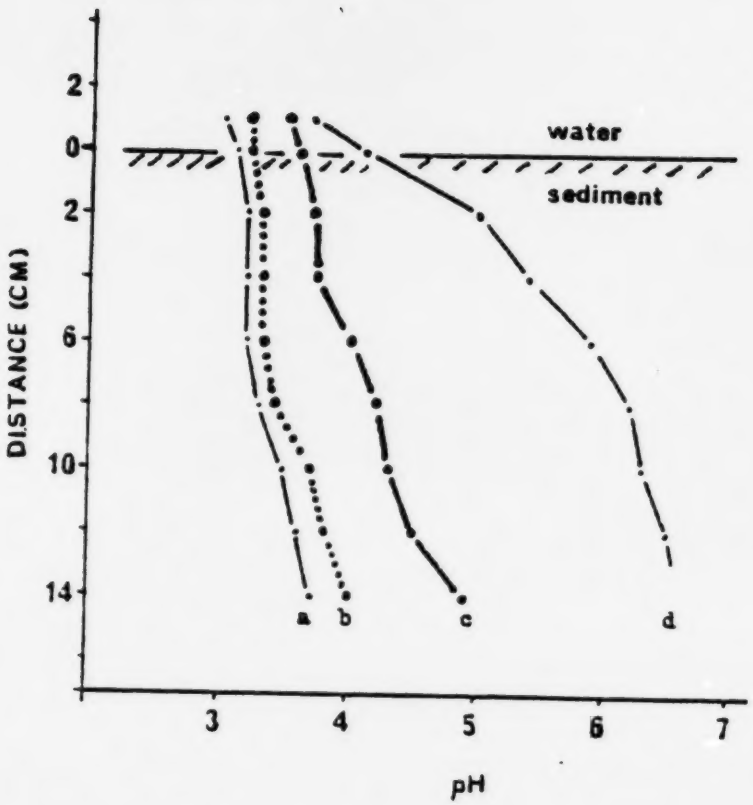

2
0
2
6
10
14
DISTANCE (CM)
water
sediment
a
b
c
d
3
4
5
6
7
pH

Table 10. Vertical profiles of selected elements in sediment cores collected from Westner Lake (1984).

DISTANCE BELOW SEDIMENT SURFACE [cm]	ELEMENTS					
	Al [ug/g]	Fe [ug/g]	Mn [ug/g]	Pb [ug/g]	Zn [ug/g]	226-Ra [pCi/g]
0 - 4	3890 ±920	27200 ±8800	21 ±4	64 ±16	87 ±50	68 ±11
5 - 8	9250 ±3560	7320 ±3500	32 ±1	86 ±14	345 ±70	54 ±12
9 - 12	11380 ±1840	4200 ±1070	46 ±17	62 ±11	305 ±10	20 ±6
13 - 16	10870 ±78	3740 ±540	99 ±32	36 ±3	186 ±13	12 ±5
17 - 20	12410 ±1020	5240 ±940	150 ±39	25 *	143 ±17	9 ±1
0 - 4 (crust)	1215	92650	8.3	81	15	5
5 - 8	1610	76850	8.3	81	68	7

Data above dotted line are means ± S.E. from four cores which had no distinct surface crust.

Data below dotted line are analyses from a single core having a distinct surface crust.

* Median: two values were below detection limit.

Table 11. Specimen counts for macro-invertebrate taxa identified in 75 twig bundles recovered from Westner Lake [1984]. Mean number per 20 twig bundles is shown in parentheses.

TAXA	COUNTS
INSECTS	
FLY LARVAE [Diptera]	
Blood Worms - Chironomidae	
Chironomini & Orthocladini	780 (208)
Biting Midges - Heleidae	
Palpomyia group	1
Water Boatmen [Hemiptera]	
Corixidae	>200 (3) ‡
Caddisfly Larvae [Trichoptera]	
Phryganeidae	27 (7.2)
Limnephilidae	17 (4.5)
Beetle Larvae [Coloeptera]	
Dytiscidae	22 (5.9)
Alderfly Larvae [Megaloptera]	
Corydalidae	1
ARACHNIDS	
Water Mites [Acarina]	
Oribatidae	>6000 (>1600)

‡ Not permanent residents of lake bottom.

from Westner Lake . The largest and most numerous of these was a member of the Family Phryganeidae provisionally assigned to the genus *Ptilostomis*. The others were limnephilids provisionally assigned to *Philarctus* and either *Limnephilus* or *Grammotaulius*.

All of the beetle larvae were from the Family Dytscidae, and all were apparently either *Agabus* or *Ilybius*.

One species from the Corixidae [water boatmen], provisionally identified as *Hesperocorixa atopodonta*, was observed and collected in all parts of Westner lake. Mature [about 25 %] or immature specimens, or both, occurred in most twig bundles, along with discarded exoskeletons and/or body fragments.

Other immature insect taxa represented in the twig bundles were a megalopteran larva [alder fly] of the genus *Chauliodes*, a heleid larva [biting midge] of the *Palpomyia* group, and a lepidopteran larva [moth] of the genus *Pyrausta*. A single water mite and a single nematode were also obtained.

Few aquatic invertebrates were obtained from the Ekman grab samples collected in 1984 [Table 12]. *Chironomus* was the most numerous, but megalopteran larvae [alder flies] of the genus *Sialis* and a corixid [water boatman] were also present. The density of organisms progressively increased from the eastern to the western end of the lake.

Although we netted Westner Lake repeatedly in 1984, neither living zooplankton nor zooplankton remains were ever obtained. It was apparent that no zooplankton was present.

Table 12. Specimen counts for insects identified in Ekman grab samples from three regions of Westner Lake.

SOURCE	TAXA	COUNTS
Eastern Third (24 Grabs)	Bloodworms [Chironomidae]	
	Chironomini: *Chironomus*	23
	Alderfly Larvae [Megaloptera]	
	Sialidae: *Sialis*	2
Central Third (16 Grabs)	Bloodworms [Chironomidae]	
	Chironomini: *Chironomus*	29
Western Third (16 Grabs)	Bloodworms [Chironomidae]	
	Chironomini: *Chironomus*	93
	Alderfly Larvae [Megaloptera]	
	Sialidae: *Sialis*	2
	Water Boatmen [Hemiptera]	
	Corixidae: *Hesperocorixa*	1*

* Not permanent residents of lake bottom.

On one occasion we observed a mature bullfrog [*Rana catesbeiana*] in the water at the edge of Westner Lake, and on one occasion we found a mature red-backed salamander [*Plethodon cinereus*] about 20 cm above the waterline. We saw no other evidence of aquatic vertebrates at this lake.

Although the water chemistry of Westner Lake changed little between 1984 and 1985, twig bundle faunas differed considerably between years [Table 13]. While oribatid mites and corixids [water boatmen] remained abundant in 1985, relatively few of the formerly dominant chironomid larvae [blood worms] were collected. *Limnophyes* continued to be present in low density, but *Chironomus* was inexplicably absent. Caddis flies also seemed to have disappeared. Two gyrinid larvae [whirlygig beetles] were collected in 1985, but no other beetles.

226-Radium in Twigs

All alder twigs analysed, whether control samples [not exposed to water], or samples recovered from Buckles Creek or Westner Lake, exhibited 226-radium analyses less than 0.1 pCi/g in both bark and wood subsamples. Thus, if 226-radium was indeed taken up, the rate was too low to be measured.

Beaver Lake

Water Quality

Tailings-influenced chemical parameters reached far higher levels in Beaver Lake than in any of the other three lakes we investigated [Tables 9 and 14].

Table 13. Specimen counts for macro-invertebrate taxa identified in 20 twig bundles recovered from Westner Lake [1985].

TAXA	COUNTS
INSECTS	
FLY LARVAE [Diptera]	
Blood Worms - Chironomidae	
Orthocladini	20
Beetle Larvae - [Coleoptera]	
Gyrinidae	2
Water Boatmen - [Hemiptera]	
Corixidae	*
ARACHNIDS	
Water Mites [Acarina]	
Oribatidae	*

* Not counted; well represented in most twig bundles.

Table 14. Water quality characteristics [x ±SE] for Beaver Lake, Lacnor Pond, Olive Lake and Westner Lake, near Elliot Lake, Ontario, as determined in 1985. Number of samples shown in parentheses.

LAKES	PARAMETERS				
	Depths Sampled m	Conductivity uS/cm	Acidity as $CaCO_3$ mg/L	Median pH	Sulfate mg/L
Beaver	0.1 (2)	4900 ±900	3070 ±300	2.4	5010 ±120
	3 - 8 (6)	>8000	5560 ±60	2.1	8080 ±380
Lacnor	0.1 - 2 (4)	1740 ±60	370 ±45	2.5	775 ±55
	3.5 (1)	2720	1080	2.6	1880
	4.5 (2)	3500 ±0	1350	4.8	3040 ±470
	6.5	3900	1240	5.6	2080
Olive	0.1 - 5 (8)	1510 ±30	225 ±3	2.7	577 ±7
Westner	0.1 - 6 (8)	560 ±10	63 ±2	3.1	210 ±7

Al mg/L	Ca mg/L	Mg mg/L	Fe mg/L	Mn mg/L	226-Ra pCi/L
108 ±22	195 ±9	42 ±5	1010 ±245	6.6 ±0.6	*
129 ±11	312 ±4	87 ±2	1810 ±115	13.6 ±0.3	*
10.7 ±0.7	87 ±1	26 ±2	93 ±8	1.6 ±0.1	19 ±3
-	200	75	320	6.3	11
0.3 ±0.04	224 ±3	101 ±4	600 ±45	8.3 ±0.2	38 ±7
0.2	260	130	570	7.7	50
8.7 ±0.2	88 ±6	18 ±1	32 ±1	1.5 ±<0.1	28 ±1
4.1 ±0.04	29 ±1	10 ±0.4	2.3 ±0.3	0.5 ±0.02	2.7 ±0.3

* Analyses voided by analytical interference effects.

Vertical stratification was evident in all chemical parameters, and a sharp chemocline existed at less than 3 m below the surface. It was not possible to determine 226-radium in this lake because our analytical methods suffered serious interferences from other substances in the samples.

Fauna

It was apparent from twig bundle analyses that Beaver Lake had a very restricted littoral fauna [Table 15]. Most samples contained a few chironomid larvae [bloodworms], but only one genus, *Chironomus*, was recorded. Shed exoskeletons of corixids [water boatmen] were present but rare. Oribatid mites occurred at low densities in about half of the twig bundles, but beetles, alder flies and caddis flies were absent.

Lacnor Pond

Water Quality

This lake exhibited water quality intermediate between that of Westner Lake and Beaver Lake, and similar to that of Olive Lake [Tables 9 and 14]. Chemical stratification was also observed here, but while most parameters were lowest near the surface, both hydrogen ion activity and aluminum concentrations decreased markedly below the chemocline.

Fauna

Relatively few taxa were obtained from the twig bundles in this lake [Table 16], but chironomid larvae [blood worms]

Table 15. Specimen counts for macro-invertebrate taxa identified in 10 twig bundles recovered from Beaver Lake [1985].

TAXA	COUNTS
INSECTS	
FLY LARVAE [Diptera]	
Blood Worms - Chironomidae	
Chironomini	37
Biting Midges - Heleidae	2
ARACHNIDS	
Water Mites [Acarina]	
Oribatidae	*

* Present, but not numerous, in 4 twig bundles.

Table 16. Specimen counts for macro-invertebrate taxa identified in 20 twig bundles recovered from Lacnor Pond [1985].

TAXA	COUNTS
INSECTS	
FLY LARVAE [Diptera]	
Blood Worms - Chironomidae	
Chironomini & Orthocladini	>2500
Beetles [Coleoptera]	
Larval Dytiscidae	3
Adult Dytiscidae	2
ARACHNIDS	
Water Mites [Acarina]	
Oribatidae	*

* Not counted. A few were present in four twig bundles.

were exceedingly numerous. *Chironomus* accounted for nearly 90% of the specimens counted, but *Limnophyes* [Orthocladini] was common. Oribatid mites, corixids [water boatmen], and both adult and larval beetles were present.

Olive Lake

Water Quality

The water quality of Olive Lake is summarized in Tables 9 and 14. Except for having higher levels of 226-radium, this lake had chemical characteristics very similar to the surface waters of Lacnor Pond. Olive Lake did not exhibit chemical stratification; in this respect it differed from Beaver Lake and Lacnor Pond but was similar to Westner Lake.

Fauna

The twig bundle fauna from this lake had both greater diversity and greater density than that in any of the other three lakes investigated [Table 17]. Almost every twig bundle contained hundreds of oribatid mites and chironomid larvae [blood worms]. While *Chironomus* was again the dominant animal, *Limnophyes* [Orthocladini] was also well represented. Beetle larvae, provisionally assigned to either *Agabus* or *Ilybius* were common, and a few gyrinid beetle larvae [whirlygigs] were also collected. A megalopteran [alder fly], a small trichopteran [caddis fly] and corixid exuviae [water boatmen] were present but rare.

Table 17. Specimen counts for macro-invertebrate taxa identified in 20 twig bundles recovered from Olive Lake [1985].

TAXA	COUNTS
INSECTS	
FLY LARVAE [Diptera]	
Blood Worms - Chironomidae	
Chironomini & Orthocladini	>9800
Caddisfly Larvae [Trichoptera]	1
Beetle Larvae [Coleoptera]	
Dytiscidae	41
Gyrinidae	7
Other	1
Alderfly Larvae [Megaloptera]	
Sialidae	2
ARACHNIDS	
Water Mites [Acarina]	
Oribatidae	*

* Not counted; numerous in all twig bundles.

DISCUSSION

Buckles Creek

Water Quality

At Station U in Buckles Creek, upstream from the Nordic Main Tailings Area, water quality was close to normal for such settings in northern Ontario [6,7]. The changes in water coloration and chemistry, expected [A.J. Vivyurka *pers. comm.*] and observed at Stations S and D, were undoubtedly a result of the creek's proximity to the Nordic Main Tailings seepage plume [1]. Although orange/yellow precipitates were indeed highly visible, seepage induced alterations in water chemistry were relatively modest.

In situ measurements of pH showed relatively little variability either upstream or downstream from Station U, and did not aid in locating points at which seepages were entering the creek. After creek water had been stored for a few days, however, changes in sample pH indicated that the most important inputs were at Station S itself, and at a point some 60m further upstream. Analysing future samples from these areas might be an efficient means of monitoring both the impacts of the seepage and its chemical evolution.

Although the seepage entering Buckles Creek was nearly neutral in pH [2], it was clearly introducing substances capable of generating acidity further downstream. The quantities of acid thus generated in 1984 were apparently small, however, since stored samples from below Station S

never exhibited pH depressions of more than 0.5 pH units. The development of yellow stains and precipitates in stored samples suggested that ferrous iron had been oxidizing to ferric hydroxide and jarosite-like minerals [5], and that these processes had contributed to sample acidification. We did not analyse for any partially-oxidized sulfur anions, such as thiosulfate or polythionates, but if such intermediates were being introduced with the seepage, they would probably have become fully oxidized, and would have further depressed sample pH by yielding sulfuric acid. Two considerations suggested that the seepage may have contained partially-oxidized sulfur. Firstly, seepage pH was apparently near 6.5 [2], and pyrite oxidation can generate considerable tetrathionate as well as sulfate in the pH range 6 - 7 [8]. Secondly, since the seepage water carried reduced (ferrous) iron [2], it was probably essentially anoxic, and anoxic sulfate bearing water could well contain partially-reduced sulfur compounds. It has been shown [8] that the oxidation of thiosulfate or polythionates present in certain ore processing effluents released near Levack, Ontario, was responsible for periodic major acidifications downstream in the Onaping River.

Future investigations should include measurements of incompletely oxidized sulfur compounds in the outer seepage plume. The resulting data would help to assess the validity of the above hypothesis, and might aid in quantifying the full acidification potential of the seepage.

Fauna

Invertebrate communities at Stations U, S and D were apparently little influenced by alterations in water chemistry. All stations had somewhat different faunas, but they each exhibited a similar degree of diversity. The presence of mayfly nymphs at Station S gave strong indication that water quality was ecologically satisfactory even within the primary seepage zone.

The occurrence of black fly larvae at Station S suggested that flow velocities tended to be greater here than at the other two stations. This, as well as altered water quality, must be considered a possible reason for the reduced numbers of ostracods and fingernail clams, for example, in the seepage area. In short, it seemed likely that subtle differences in physical rather than chemical limnology had been responsible for a number of the faunal differences observed between stations.

In view of the several indications that water quality was impaired very little in Buckles Creek, it was surprising that no fish, amphibians or crayfish were obtained from Buckles Creek in 1984. All three had been observed there in 1983 [4], and their absence remains unexplained.

On the assumption that the Nordic Main Tailings seepage plume will continue to advance southward, the influence of seepages in Buckles Creek will likely become gradually more significant. Periodic faunal studies would be useful in documenting specific biological impacts, if and when they occur, and would help to indicate the relative environmental significance of changes in seepage quality.

Westner Lake

Water Quality

Water quality in Westner Lake was clearly impaired by chemical inputs from the Nordic West Arm Tailings. While water of excellent quality was probably entering from most of the watershed, as evidenced by analyses of the inflowing creek, its influence was insufficient to ameliorate the effects of the seepage. Aluminum, iron and manganese concentrations and pH were consistently at ecologically unsatisfactory levels in the lake water [9].

Lead, uranium and 226-radium were present in the inflowing seepage, but only very low concentrations were recorded in the lake water. Data on water quality within the Nordic West Arm Tailings Area [3] suggest that, as seepage waters continue to move westward, the concentrations of chemicals entering Westner Lake could become increasingly greater. If this does occur, levels of 226-radium and other radionuclides in the lake could become significant.

Water discharging from Westner Lake was unsatisfactory in terms of pH and aluminum concentrations [9] as far downstream as Station 0. The consequences of this situation are being investigated as part of another study, but this work is not yet complete.

Sediment Quality

In a study of acidic lakes in northeastern Ontario that were not receiving acidic effluents directly, sediments were typically found to be acidified to depths of 1-2cm [14]. In

contrast, the sediments of Westner Lake were generally highly acidified to depths exceeding 12 cm. Maximum down-core values suggested that sediment pH had originally been near 6.5 in Westner Lake, and this value was near the mode for lakes in northeastern Ontario [14]. Such data strongly suggested that the normal buffering capacity of Westner Lake's sediments had been essentially exhausted.

The accumulation of iron in and on the surficial sediments of Westner Lake was consistent with the high iron concentrations in the seepage, the general occurrence of yellow/orange precipitates and crusts, and the high oxygen concentrations in the water. These accumulations were not considered exceptionally great, however, except in the crusts themselves. Profundal lake sediments in the greater Sudbury area, for example, have been shown to have surficial iron concentrations of 20,000 - 60,000 ug/g [10]. Sediment accumulations of lead undoubtedly reflected the very low solubility and low biogeochemical mobility of this metal [11]. Comparisons may be made with sediments that have previously been analysed from several lakes in the Algoma district that were relatively remote from urban or industrial areas [12]. In these lakes, where lead was assumed to have arrived via long range atmospheric transport, surficial sediments had total lead concentrations of 150-250 ug/g dry weight, and the minima in down-core sediments were < 5 ug/g. Thus, Westner Lake sediments exhibited relatively modest lead concentrations, and actually may have been losing lead to the overlying water.

Data from the sediment core having a complete surface crust suggested that lead precipitation was associated with iron precipitation. Since 226-radium was at low levels in the iron-rich crust, its general accumulation in the upper sediments was apparently unrelated to iron chemistry. Surficial sediments from Wollaston Lake, Saskatchewan [13], were found to have 226-radium enrichments in one area that were much higher than those in Westner Lake sediments.

Westner Lake sediments had down-core concentrations of aluminum and zinc similar to those in the Algoma lakes mentioned above [12]. Sediment manganese concentrations were extremely variable among the Algoma lakes, but unlike the situation in Westner Lake, surface concentrations were always much greater than down-core concentrations [12]. Aluminum concentrations showed little vertical pattern in the Algoma lakes' sediments, but zinc concentrations were highest at the sediment surface [12]. Since aluminum, manganese and zinc all occurred at relatively low concentrations in the upper strata of Westner Lake's sediments, these metals apparently had been/were being allowed to diffuse into the overlying water as the lake bottom acidified. If this interpretation is correct, then lake acidification has caused watershed exports of metals to increase, and there will have been a degree of metal enrichment in other aquatic environments downstream.

Fauna

Both crustacean zooplankton and aquatic vertebrates are intolerant of low pH, and hence their absence from Westner Lake was not unusual. The larvae of the common insect *Chaoborus* [phantom midges] are planktonic, but being predaceous they would not have found a food supply in this lake, even if they could have tolerated the water chemistry. Thus, the absence of these plankters was also predictable.

In view of the prejudicial water and sediment quality in Westner Lake, it supported an interesting assemblage of non-planktonic arthropods, and at least a short food chain. Most of the animals recovered from twig bundles and Ekman grab samples were believed to be detritivores or micro-herbivores [oribatid mites, chironomids and corixids], but the beetle and megalopteran larvae were predators. The food habits of the trichopterans were unclear, but *Ptilostomis* species are commonly omnivorous.

It was significant that we observed chironomid pupae, late-stage beetle larvae, late-stage trichpterans, and nymphal corixids. The presence of such specimens indicated that these insects were successfully completing all aquatic stages of their life cycles within Westner Lake, and were indeed highly tolerant of the unusual water quality.

226-Radium in Twigs

The failure of alder twigs to concentrate 226-radium, during an exposure of about one month, suggested that plant detritus had little ability to absorb this element from the waters of Westner Lake. In unproductive lakes, and especially in small ones like Westner Lake, organic detritus from the surrounding forest is commonly a major source of nutrition for the littoral zone invertebrates. If plant material had shown a significant ability to concentrate 226-radium, it would have suggested a major factor to consider in assessing radium bio-availabilty.

Beaver Lake

Water Quality

The low pH and high metal concentrations recorded from Beaver Lake indicated that this was a most inhospitable aquatic environment, even above the chemocline. These key parameters implied that ecologically Beaver Lake was more impaired than Westner Lake by at least an order of magnitude.

Fauna

The occurrence of *Chironomus* and oribatid mites in Beaver Lake was indisputable testimony to their exceptional tolerance to the constituents of tailings effluents. Their low densities were probably a result of the harsh chemical environment, but other factors such as poor nutrition should not be entirely discounted.

Lacnor Pond and Olive Lake

Water Quality

Water analyses indicated that the upper 2m of Lacnor Pond and Olive Lake were chemically very similar, and that these waters were intermediate between Westner Lake and Beaver Lake in terms of relative impairment. This generality may not apply to 226-radium, however, since relevant data were not obtained for Beaver Lake. The similarities in surface waters between these lakes may reflect the fact that both were in contact with tailings, but since Lacnor Pond exhibited chemical stratification and Olive Lake did not, these similarities were probably fortuitous.

Fauna

The high densities of chironomids in twig bundles from both Lacnor Pond and Olive Lake, compared to densities of the same genera in Westner Lake, was most interesting. This situation indicated that water quality impairment had not been limiting the abundance of chironomids in Westner Lake, and that nutritional or other factors were more significant. Since beetle larvae were collected in both Lacnor Pond and Olive Lake, their chironomid populations were not simply large because they were free of predation.

Lake Faunas Compared

The invertebrate animals that were tolerant to uranium tailings effluents generally seemed to be members of the same species from lake to lake. Although it was not often possible to carry identifications to the species level, it is likely that different "types" would have been noted if different species had been present. Thus, detailed studies carried out in one tailings-influenced lake should have wide applicability to others, and it did not appear that tolerant taxa were adapting to impairments on a lake by lake basis.

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